1 **Site selection of ocean current power generation from drifter**

2 **measurements**

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14. ABSTRACT

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27 Japan, Vietnam, Taiwan, and Philippines have suitable sites for the development of ocean

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29 and 1.0 m s^{-1}, respectively. Vietnam has a better bottom topography to develop the current

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36 successfully operated in Taiwan, more current power plants can be built in these waters.

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38 Keywords: SVP drifter, ocean current, power generation, the East Asia, Kuroshio

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1. Introduction

Ocean current power is generated from the kinetic energy of ocean currents with less uncertainty than the wind, wave and solar power, and has the high load capacity resulting from the high density of fluid (seawater) [1－3]. Electric power generation from global ocean currents has enormous potential. In 2000, Blue Energy, Inc., estimated that global ocean currents have capacity over 450 GW and represent a market of approximately US$550 billion per annum (assuming purchase price per kWh = US$0.1395) [4]. However, it is noted that devices which extract power from a fluid's momentum (e.g. a tidal turbine or wind turbine) can realistically reach an efficiency up to 50% (the Betz limit is a bit higher, but not by a great deal).

There are many world-wide sites with tidal velocities of 2.5 m s^{-1} and greater. Countries with an exceptionally high resource include the UK, Italy, Philippines, and Japan [4]. But strong tidal currents only last for a short time period, and cannot provide a stable power supply. The strong Florida Current and Gulf Stream move close to the shore of the United States [5-6] in areas of high demand for power [4]. Earlier studies [7－8] indicated that the westward recirculations steadily increase the transport of the Gulf Stream from approximately 30 Sv (1 Sv = 10^6 m^3 s^{-1}) in the Florida Current to approximately 150 Sv at 55°W. The transport is around 20–30 Sv for the Kuroshio near

59   Taiwan, and about 4–10 GW of ocean current power are generated with the flow velocity

60   of 1 m s^{-1} [9].

61   In Taiwan, the Kuroshio power plant of 30MW was planned between Taitung and

62   Green Island (~121.43°E, 22.70°N, see Fig. 1) [9]. The estimated annual net income of

63   power plant is 488.58 million NTD (new Taiwan dollar, 1 USD ~ 31 NTD). The payback

64   period is only 6.2 years. The estimated power plant life is 20 years. Thus, the Kuroshio

65   power plant in Taiwan will be operated successfully in the future. Questions arise: Are

66   there other sites or locations in the East Asia suitable for the development of the

67   (Kuroshio) current power generation? If yes, where are these sites? Ocean flow

68   measurement data is an important factor in selecting the site of ocean current power

69   generation. The purpose of this paper is to determine possible sites of current power plant

70   for technical and economic feasibility, and to develop a complete map of strong currents

71   in the East Asia using the Surface Velocity Program (SVP) drifter data of Global Drifter

72   Program (GDP). The GDP is the principle component of the Global Surface Drifting

73   Buoy Array, a branch of the NOAA Global Ocean Observing System (GOOS) and a

74   scientific project of the Data Buoy Cooperation Panel (DBCP).

75

76   **2. Data and Method**

77   The NOAA Drifter Data Assembly Center (DAC) provides quality controlled data for

78   velocity measurements. Upper ocean current velocities every 6 h can be   obtained from

79   the website: http://www.aoml.noaa.gov/phod/dac/dacdata.php.   A total of 1,883 drifters

80   in the northwestern Pacific (10°–50°N, 100°–150°E) during 1985–2009 are used for this

81   study (see Fig. 2). There are 1,029,889 six-hourly velocity observations of SVP drifters in

82   the study area. All drifters had a holey-sock drogue centered at a nominal depth of 15 m.

83   The 6 hourly velocities are obtained via 12 h centered differencing of the kriged positions

84   [10]. The estimated accuracy of the velocity measurements using SVP drifters is 0.01 m

85   s^{-1} with surface winds of 10 m s^{-1} [11].

86

87   **3. Site Selection**

88   3.1 Four factors of site selection

89   Four factors related to the site selection of ocean current power generation [9] are (1)

90   near coast, (2) shallow seabed, (3) stable flow velocity, and (4) high flow speed,

91   respectively. Near-shore or shallow-water facilities require less cost of construction and

92   maintenance. High and stable flow speeds can provide the great and steady power in

93   comparison tidal current power generation (short period strong currents). The distance

94   from shore (L) can be calculated from the coastline data of NOAA National Geophysical

95   Data Center (NGDC). The depth (D) data can also be obtained from the NOAA/NGDC.

96   The drifter locations and velocities can be downloaded online at the NOAA/DAC website.

97   The ensemble of the individual drifter locations is plotted in Fig. 2 with color coded in

98   accordance with the local instantaneous speed. The strongest current of the Northwestern

99   Pacific is the Kuroshio. Formed from branching of the North Equatorial Current, the

100 Kuroshio is intensified east of Luzon and Taiwan [12]. Figure 3 shows the numbers of

101 data point in $0.25° \times 0.25°$ bins and their standard deviation. The ensemble mean current

102 speed (Fig. 4) and velocity vectors (Fig. 5) are computed using the bin average method

103 [13−14] in $0.25° \times 0.25°$ bins and is shown only for bins with more than 7 observations.

104 The Kuroshio axis is along the east coast of Luzon, Taiwan and Japan. Drifter-measured

105 velocities (U) are often greater than 1.2 m s^{-1} in the Kuroshio axis (Fig. 2).   Besides

106 Kuroshio, there is a strong current with a velocity of 1.2 m s^{-1} in the South China Sea

107 along the coast of Vietnam. Fig. 4 shows the average speeds of strong currents near Japan,

108 Vietnam, Taiwan, and Philippines, reaching 1.4, 1.2, 1.1, and 1.0 m s^{-1}, respectively. A

109 complete map of strong ocean currents is obtained from 25 years (1985−2009) of direct

110 velocity measurements for the site selection of ocean current power generation in the East

111 Asia. Thus, Japan, Vietnam, Taiwan, and Philippines (Figs. 4 and 5) have a good

112 condition (U>1.0 m s^{-1}) for developing the ocean current power generation.

113   Percentages of current speed greater than 1 m s^{-1} (i.e., percentage of good quality of

114   power supply) in $0.25° \times 0.25°$ bins (Fig. 6) can reach $55-80\%$ (~$13.2-19.2$ hours/day)

115   in some locations near Japan, Taiwan, Vietnam, and Philippines. Fig. 7 shows the

116   seasonal variation of current speeds with the mean current speeds in winter half-year

117   (from October to March) and in summer half-year (from April to September). The

118   locations of strong currents along the east coast of Luzon, Taiwan and Japan are almost

119   the same in winter half-year as in summer half-year. But, the mean current speeds are 0.1

120   -0.2 m s^{-1} greater in summer half-year than in winter half-year. Thus the power plant

121   will generate more electricity in summer half-year. The observed current data near

122   Vietnam is less in summer half-year, but strong currents (>1.0 m s^{-1}) were measured

123   along the east coast of Vietnam in both winter and summer half-years.

124

125   **3.2 Index *I***

126   In the recent study [4], the mid-water energy production units (EPUs) with a

127   retention–transmission cable system will lie $6-37$ km offshore of southeast Florida in

128   about $100-500$ m of water. In Taiwan, the anchor system for the deep water of more

129   than 500 m is also being developed for Kuroshio power plant near Taitung [9]. The sea

130   depth near Taitung is often more than 500 m. Thus the anchor chain length must be over

131   a thousand meter. The relay platform is a flexible structure floating in the deep sea [15].

132   Existing turbines with vertical axis may be suitable for the Kuroshio plant [9]. Because its

133   construction and maintenance cost is lowest for deep-sea engineering. Thus turbine

134   generators and anchor system for the deep water may be able to work successfully in the

135   next few years. In order to objectively consider four factors of site selection, an index I

136   related to the site selecting of current power generation is designed as

137
$$I = \sum_{i=1}^{4} I_i w_i, \tag{1}$$

138    $I_1=[1-(L/50\ km)]$, $I_2=[1+(D/1000\ m)]$, $I_3=P/100\%$, $I_4=U/1.4\ m\ s^{-1}$.

139   Here, P is the percentage of current speed greater than 1 m s^{-1}; U is the current speed. The

140   choice of constants (L = 50 km, D = 1000 m, and U = 1.4 m s^{-1}) is based on the

141   aforementioned studies [4] [9] and a maximum of mean speeds in Fig. 4. Each of these

142   indices was weighted to reflect their impact on revenue, capital costs, and maintenance

143   costs, etc. According to the recent study [9], the plant engineering of a 30 MW pilot plant

144   needs a total investment fund of 2.3 billion NTD. The operation expenses, include

145   maintenance costs, personnel costs, insurance, etc., is 0.12 billion NTD dollars a year.

146   If the plant life is 20 years, the operation expenses of 20 years is 2.4 billion NTD. Thus

147   the capital and maintenance costs of 20 years are about 4.7 billion NTD. The sales

148   income of a 30 MW plant is 30,000 kW × 20 (years) × 365 (day/year) × 24 (h/day) ×

149   0.7 (assuming capacity = 70%) × 2.8 (NTD/kWh, purchase price per kWh= 2.8 NTD) =

150   10.3 billion NTD [9]. Thus, percentages of expenditure and income were 31% (4.7 billion

151   NTD) and 69% (10.3 billion NTD), respectively. I_1 and I_2 reflect their impact on

152   expenditure. I_3 and I_4 reflect their impact on revenue. Hence w_1 and w_2 are set to be

153   15.5%, then w_3 and w_4 are set to be 34.5%. Each index of site selection ranged from 0 to

154   1. The variations of I_1, I_2, I_3, and I_4 are shown in the Fig. 8. The   variation of the index I

155   is shown in the Fig. 9. The higher the index value is, the more suitable the site of ocean

156   current power generation selects. The recent study [9] suggests the four factors of site

157   selection in priority order: (1) near coast (I_1), (2) shallow seabed (I_2), (3) stable flow

158   velocity (I_3), and (4) high flow speed (I_4). Thus the ranges of four factors (or four indexes,

159     $I_1 - I_4$) were limited to select suitable sites of ocean current power generation in the

160   following paragraph. Firstly, 76 sites, which meet initial conditions (L<100 km (I_1>-1),

161   D<2000 m (I_2>-1), P>30% (I_3>0.3), and U>0.7 m s^{-1} (I_4>0.5)), and their I values are

162   shown in Fig. 10a. These sites located in the east of Vietnam, northeast of Luzon, east of

163   Taiwan and south of Japan (in red boxes of Fig. 10a). The site of Kuroshio power plant

164   near Green Island in the recent study [9] is also selected in these conditions.   If L is

165   reduced to 50 km (L<50 km; I_1>0), the selected sites become less in amount (46 sites), as

166   shown in Fig. 10b. Shorter L will significantly reduce engineering and maintenance costs.

167   The site of Kuroshio power plant near Green Island is still one of selected sites. If D is

168   reduced from 2000 m to 1000 m (D<1000 m; I_2>0), only 21 sites are selected, as shown

169   in Fig. 10c. Selecting a site in shallower waters will greatly increase the chances of

170   successful operation, because developing an anchor system for the shallower water is

171   easier. As D<1000 m, the site of Kuroshio power plant near Green Island is not selected.

172   Finally, if P and U are increased to 50% and 1 m s^{-1} (I_3>0.5, and I_4>0.714), respectively,

173   income and power generation of plant will greatly increase. In Fig. 10d, the most suitable

174   sites are selected for the development of ocean current power generation in the East Asia.

175   There are 12 sites are selected according to the conditions of L<50 km, D<1000 m,

176   P>50%, and U>1.0 m s^{-1}. The information of the 12 sites is listed in Table 1. There are

177   seven sites (V1－V7) near Vietnam, three sites (J1－J3) near Japan, and 2 sites near

178   Taiwan (T1) and Philippines (P1).　Their index I values are 0.539－0.726 (V1－V7,

179   Vietnam), 0.518－0.607 (J1－J3, Japan), 0.540 (T1, Taiwan), and 0.538 (P1, Philippines),

180   respectively. This suggests that the most suitable region to develop the ocean current

181   power generation is the shallow coastal water near Vietnam, and then is followed by

182   Japan, Taiwan and the Philippines. The detail descriptions for each index are listed in

183   Table 2.

184   In order to show clearly the correct position of 12 sites with strong currents,

185   enlargements of mean current speed from Fig. 4 with the isobaths near Japan, Taiwan,

186   Vietnam, and Philippines, respectively, are plotted in Fig. 11. Sites V1 (109.5°E, 14.0°N),

187   V6 (109.5°E, 11.75°N) and V7 (109.5°E, 11.5°N) are selected approximately 30 km east of

188   Vietnam on the shelf (Table 1 and Fig. 11a). Water depths at V1, V6, and V7 are only 160,

189   120, and 100 m, respectively (see Table 1). The three sites have higher I_2 values (0.84,

190   0.88, and 0.90), which are much greater than those of other sites. Then, V6, V1, and V7

191   have three highest I values (see Table 2). Thus the shallow seabed (D<200 m) is an

192   important parameter to influence the choice Vietnam over the others. Mid-water EPUs

193   can work in approximately $100-500$ m of water in recent study [4]. Thus it is easier to

194   build a current power plant near Vietnam in the future. Sites $V2-V5$ are selected about

195   40 km east of Vietnam with the current speeds of about 1.2 m s^{-1} (U), and depths (D) of

196    $700-900$ m (see Table 1, and Fig. 11a). At these sites, there are stronger current speeds

197   and deeper depths. Approximately 60% of observed speeds are greater than 1 m s^{-1} at

198   these sites. Sites J1, J2, and J3 are selected about 40 km south of Shikoku, Japan with the

199   U of 1.1 m s^{-1}, and D of $560-850$ m (Fig. 11b). Site T1 is selected about 29 km east of

200   Yilan, Taiwan (122.25°E, 24.5°N) with an average current speed of 1.0 m s^{-1} on the slope

201   (D~650 m) (Fig. 11c).   About 50% of all measured currents speeds are greater than 1 m

202   s^{-1}. Finally, site P1 near Philippines is selected about 30 km northeast of Palaui Island

203   (122.5°E, 18.75°N) with an average current speed of 1.0 m s^{-1} (Fig. 11d). Approximately

204   55% of all observed speeds are greater than 1 m s^{-1}. Sites T1 and P1 located in the

205   Kuroshio axis (see Figs. 11c and 11d). In Taiwan, the Kuroshio power generation was

206   planned to build in the waters between Taitung and Green Island [9]. After the Kuroshio

207   power plant is operated successfully in the near future, more current power plants can be

208   built in the 12 suitable sites near Vietnam, Japan, Taiwan, and Philippines.

209

210   **4. Summary**

211   The charts of mean current speeds and 12 suitable sites in the East Asia are provided

212   for the development of ocean current power generation from analyzing   the SVP drifter

213   current data (1985－2009). In the future, current power plants can be built in the regions

214   of Vietnam, Japan, Taiwan, and Philippines. The United Nations Intergovernmental Panel

215   on Climate Change (IPCC) has released its synthesis report, which can be obtained from

216   http://www.ipcc.ch/pdf/assessment-report/ar5/syr/SYR_AR5_LONGERREPORT.pdf.

217   The report warns that greenhouse gas levels are at their highest in at least 800,000 years,

218   and continued emission of greenhouse gases will cause irreversible impacts for people

219   and ecosystems. The application of ocean current power generation will help to reduce

220   greenhouse gas emissions.

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Acknowledgements

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References

[1] Bahaj AS, Generating electricity from the oceans, Renewable and Sustainable Energy Reviews, 2011;15:3399-3416.

[2] Zodiatis G., Galanis G, Nikolaidis A, Kalogeri C, Hayes D, Georgiou GC, Chu PC, Kallos G, Wave Energy Potential in the Eastern Mediterranean Levantine Basin-An integrated 10-year study. *Renewable Energy*, 2014: **69:** 311-323.

[3] Ponta FL, Jacovkis PM, Marine-current power generation by diffuser-augmented floating hydro-turbines, Renewable Energy, 2008;33:665-673.

[4] Finkl CW, Charlier R, Electrical power generation from ocean currents in the Straits of Florida: Some environmental considerations, Renewable and Sustainable Energy Reviews, 2009;13:2597-2604.

239   [5] Chu PC,   Statistical characteristics of the global surface current speeds obtained

240   from satellite altimeter and scatterometer data, IEEE Journal of Selected Topics in Earth

241   Observations and Remote Sensing, 2009; 2 (1): 27-32.

242   [6] Chang YC, Tseng RS,   Chen GY,   Chu PC, Shen YT, Ship routing utilizing strong

243   ocean currents, Journal of Navigation, 2013; 60**:** doi:10.1017/ S0373463313000441

244   [7] Hendry RM, On the structure of the deep Gulf Stream. Journal of Marine Research,

245   1982;40:119-142.

246   [8] Hogg NG, On the transport of the Gulf Stream between Cape Hatteras and the Grand

247   Banks. Deep-Sea Research, 1992;39:1231-1246.

248   [9] Chen F, Kuroshio power plant development plan, Renewable and Sustainable Energy

249   Reviews, 2010;14:2655-2668.

250   [10] Hansen D, Poulain PM, Quality control and interpolations of WOCE-TOGA drifter

251   data, Journal of Atmospheric and   Oceanic Technology, 1996; 13, 900–909.

252   [11] Niiler PP, Sybrandy AS, Bi K, Poulain PM, and Bitterman D, Measurements of the

253   water following capability of holey-sock and TRISTAR drifters. Deep-Sea Research

254   1995;42A:1951–1964.

255   [12] Chu PC, Li RF, You XB, Northwest Pacific subtropical contercurrent on isopycnal

256   surface in Summer, Geophysical Research Letters 2002;   **29:** 10.1029/2002GLO14831.

257   [13] Centurioni LR, Niiler PP, On the surface currents of the Caribbean Sea, Geophysical

258   Research Letter 2003; 30:1279, doi:10.1029/2002GL016231.

259   [14] Centurioni LR, Niiler PP, Lee DK, Observations of inflow of Philippine Sea surface

260   water into the South China Sea through the Luzon Strait, Journal of Physical

261   Oceanography 2004; 34:113-121.

262   [15] Chen F, The Kuroshio Power Plant, Springer International Publishing, 1st edition,

263   2013; pp 320.

264

265   **List of Tables**

266   Table 1. Twelve suitable locations (L<50 km, D<1000 m, P>50%, and U>1 m s^{-1}) for

267   development of ocean current power generation

Site	Country	Location	Distance, L (km)	Depth, D (m)	Percentage, P (%)	Speed, U (m s^{-1})
V1	Vietnam	109.50 ° E, 14.00°N	19 km	-160 m	55% (> 1 m s^{-1})	1.05 m s^{-1}
V2	Vietnam	109.75 ° E, 12.75°N	33 km	-960 m	62%	1.26 m s^{-1}
V3	Vietnam	109.75 ° E, 12.50°N	33 km	-890 m	60%	1.20 m s^{-1}
V4	Vietnam	109.75 ° E, 12.25°N	39 km	-790 m	51%	1.20 m s^{-1}
V5	Vietnam	109.75 ° E, 12.00°N	46 km	-680 m	58%	1.25 m s^{-1}

V6	Vietnam	109.50 ° E, 11.75°N	28 km	-120 m	63%	1.23 m s^{-1}
V7	Vietnam	109.50 ° E, 11.50°N	38 km	-100 m	58%	1.12 m s^{-1}
J1	Japan	134.75 ° E, 33.25°N	41 km	-850 m	64%	1.15 m s^{-1}
J2	Japan	133.50 ° E, 32.75°N	41 km	-710 m	54%	1.05 m s^{-1}
J3	Japan	133.25 ° E, 33.50°N	38 km	-560 m	64%	1.13 m s^{-1}
T1	Taiwan	122.25 ° E, 24.50°N	29 km	-650 m	50%	1.01 m s^{-1}
P1	Philippines	122.25 ° E, 18.75°N	23 km	-960 m	55%	1.05 m s^{-1}

268

269   Table 2.   Index *I* for selecting the site of ocean current power generation

No.	Site	I_1 [1-L/50 km]	I_2 [1+D/1000 m]	I_3 [P/100%]	I_4 [U/1.4 m s^{-1}]	I
1	V6	0.44	0.88	0.63	0.88	0.726
2	V1	0.62	0.84	0.55	0.75	0.675
3	V7	0.24	0.90	0.58	0.80	0.653
4	J3	0.25	0.44	0.64	0.81	0.607
5	V2	0.34	0.04	0.62	0.90	0.583
6	V3	0.34	0.11	0.60	0.86	0.574
7	V5	0.09	0.32	0.58	0.89	0.571

8	J1	0.18	0.15	0.64	0.82	0.555
9	T1	0.42	0.35	0.50	0.72	0.540
10	V4	0.22	0.21	0.51	0.86	0.539
11	P1	0.54	0.04	0.55	0.75	0.538
12	J2	0.18	0.29	0.54	0.75	0.518

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271 **List of Figures**
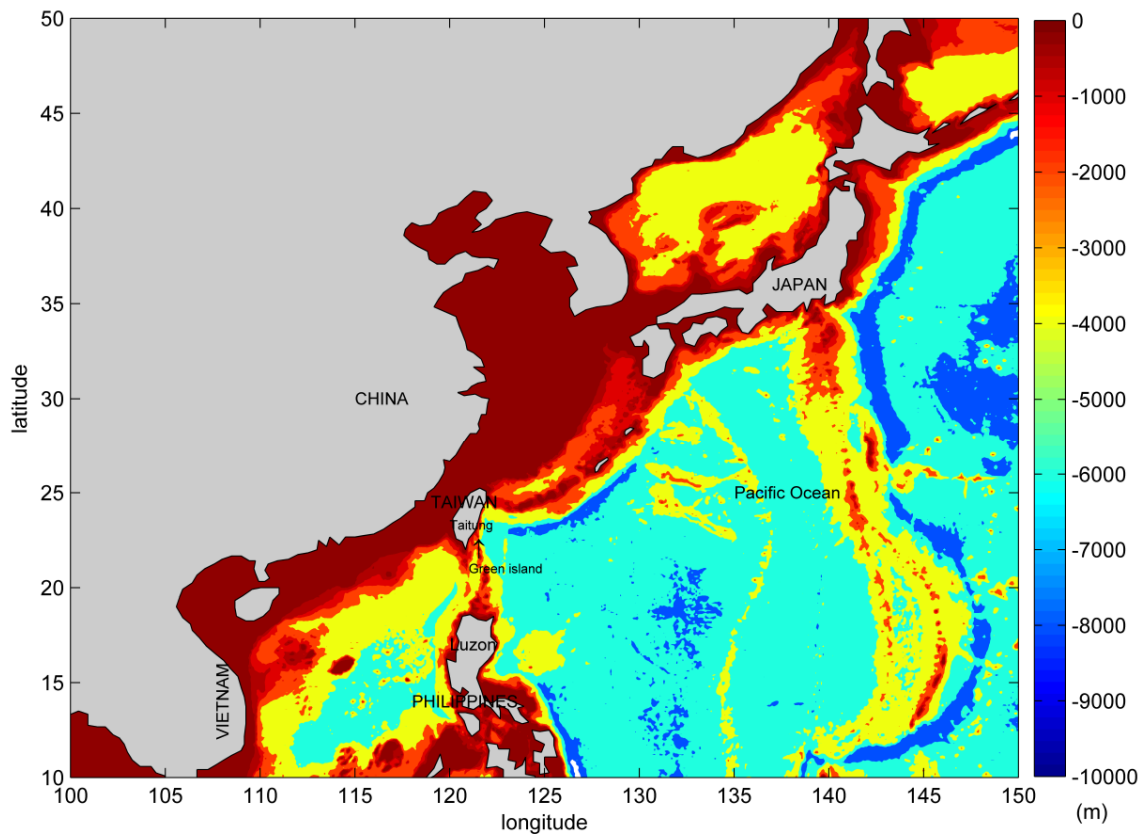
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273   Figure 1. Geography and bottom topography of the East Asia.

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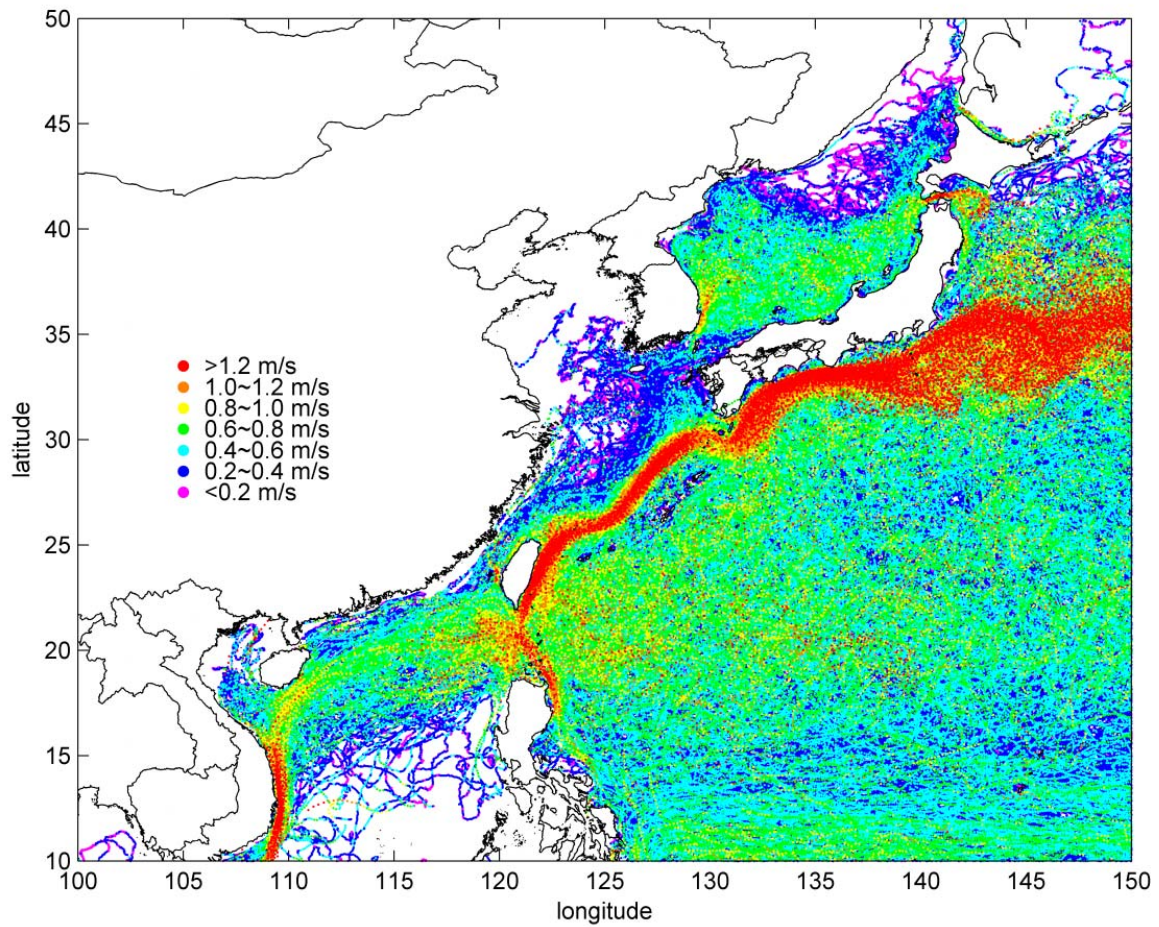
275 Figure 2. Locations of drifters with color-coded in accordance with their 6-hourly

276 instantaneous speed.

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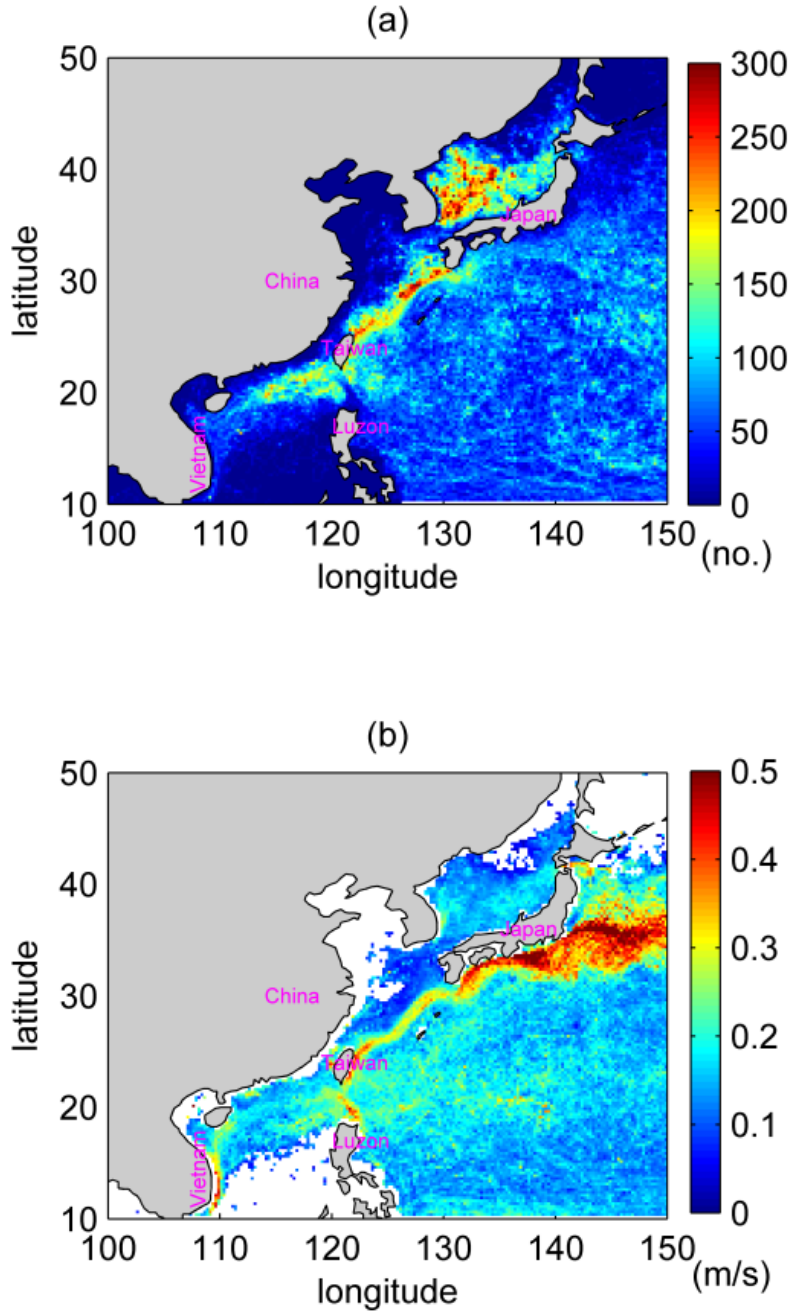
279   Figure 3. (a) Numbers of data point in $0.25° \times 0.25°$ bins and (b) their standard deviation

280   (m s^{-1}).

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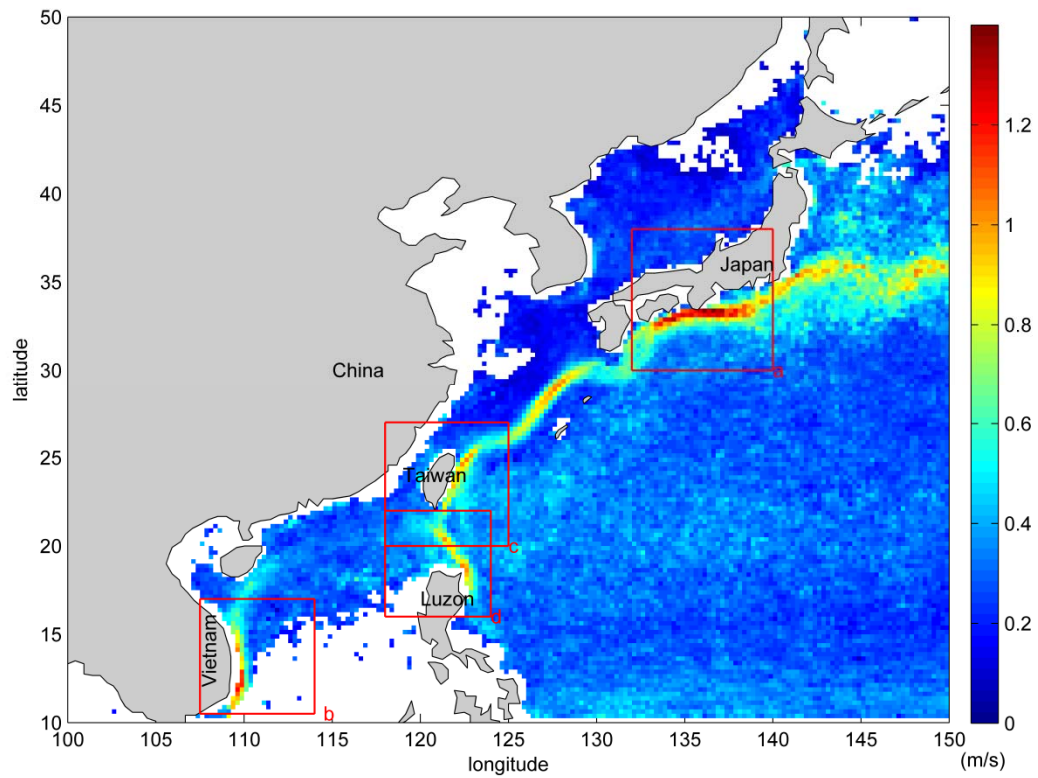
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284   Figure 4. Averaged drifter speeds (unit: m s^{-1}) in $0.25° \times 0.25°$ bins.

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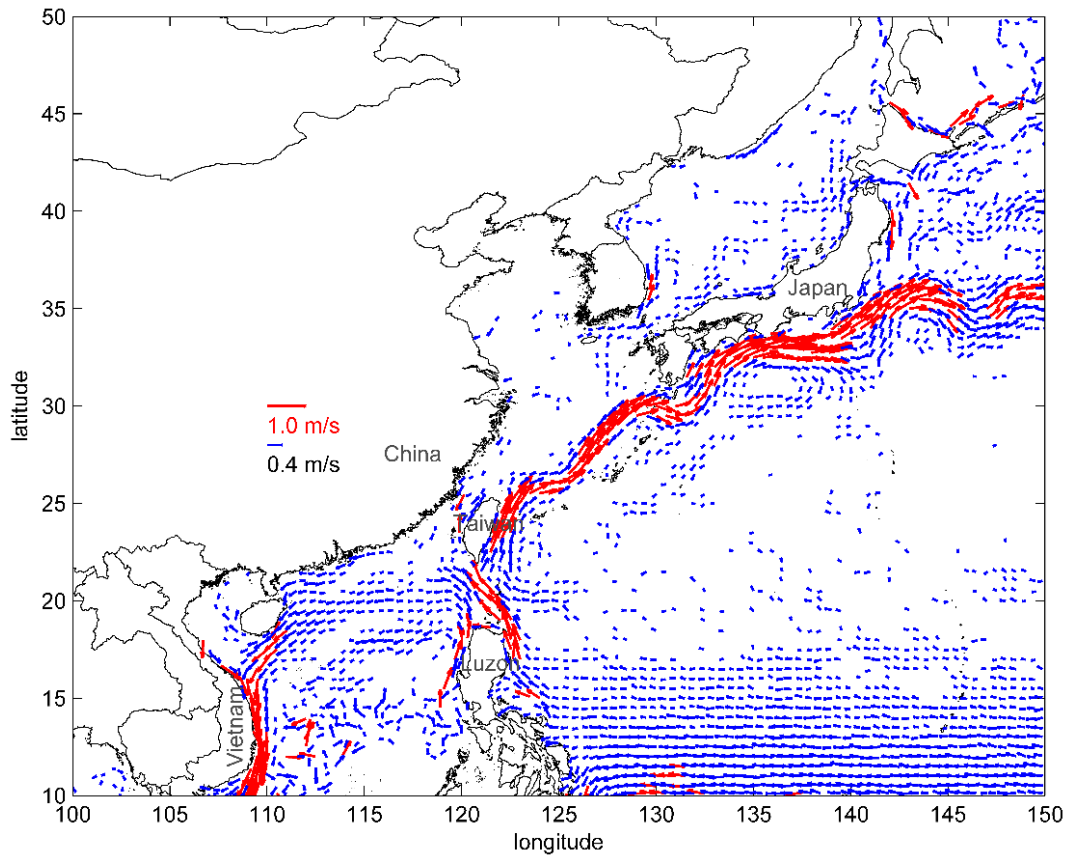
Figure 5. Averaged drifter velocities. Speeds higher and lower than 0.4 m s^{-1} are shown in

red and blue, respectively.

289
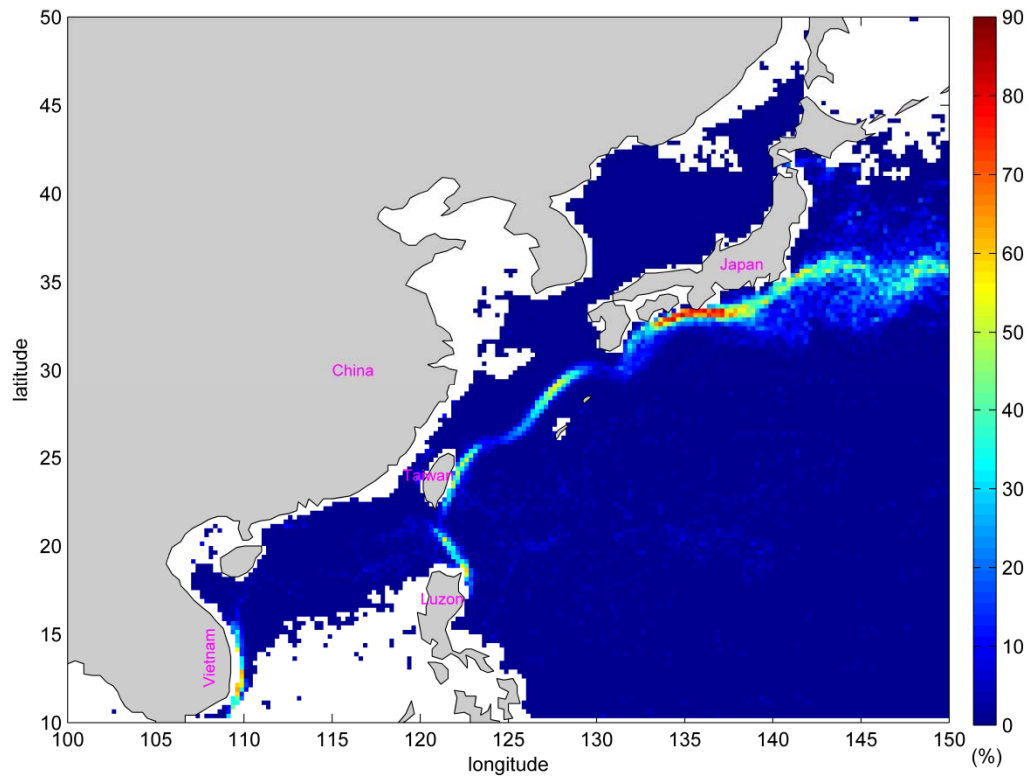
290

291   Figure 6. Percentages of current speed greater than 1 m s^{-1} in $0.25° \times 0.25°$ bins.

292
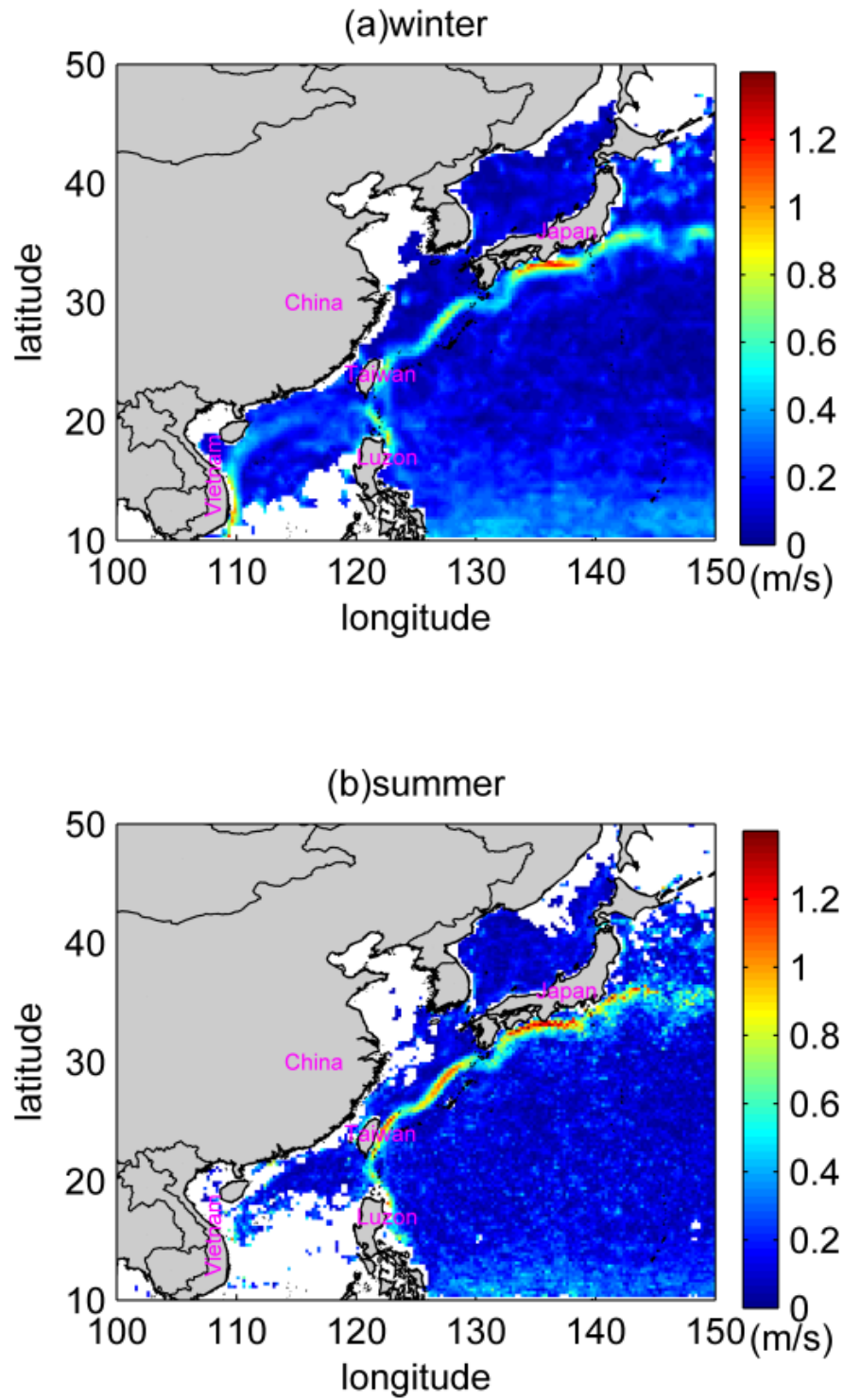
293

294   Figure 7. Averaged drifter speeds (unit: m s^{-1}) (a) in winter half-year and (b) in summer

295   half-year.
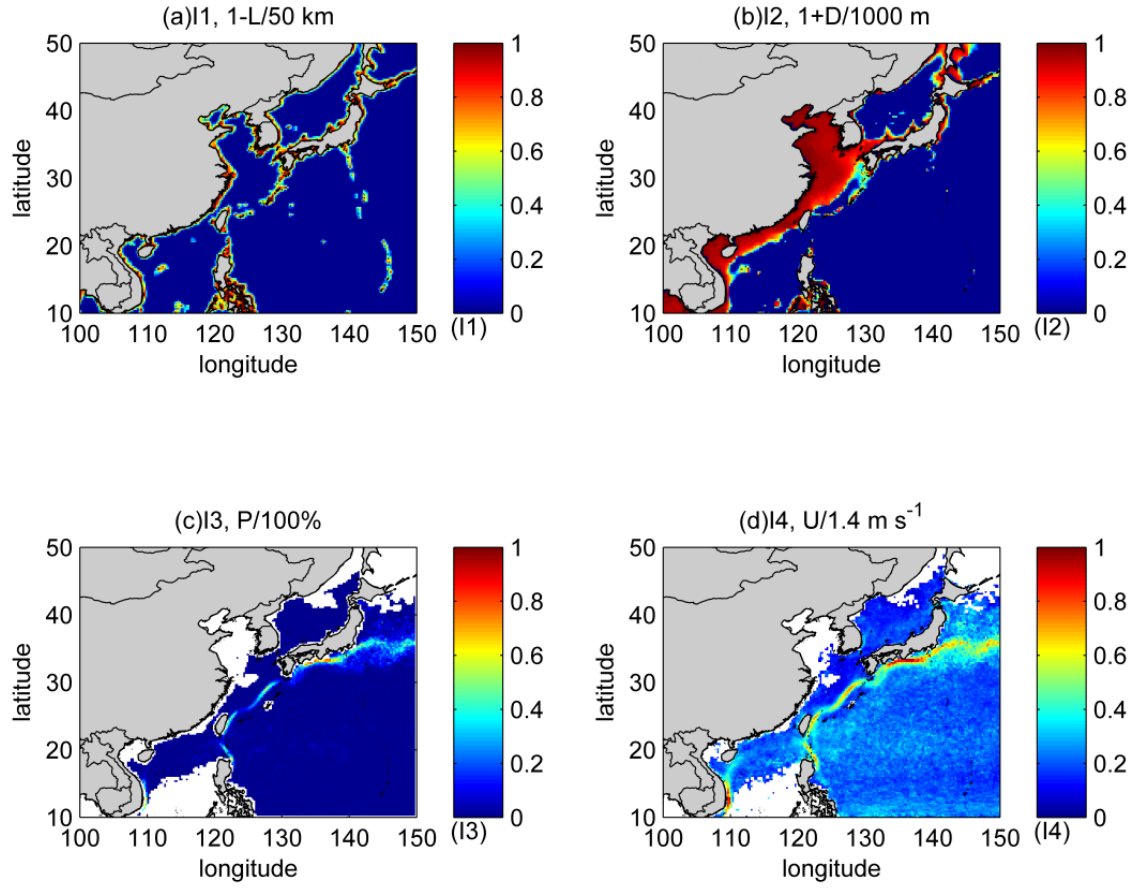
296

297   Figure 8. Distributions of index I_1, I_2, I_3, and I_4 in the East Asia
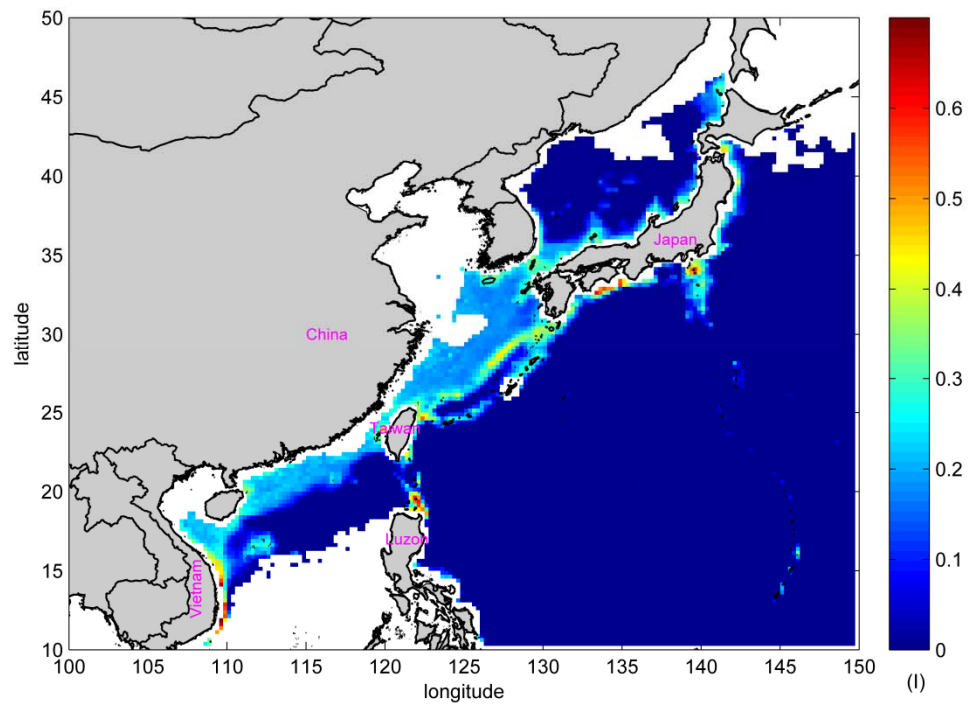
298

299   Figure 9. Distribution of index I in the East Asia

300

301
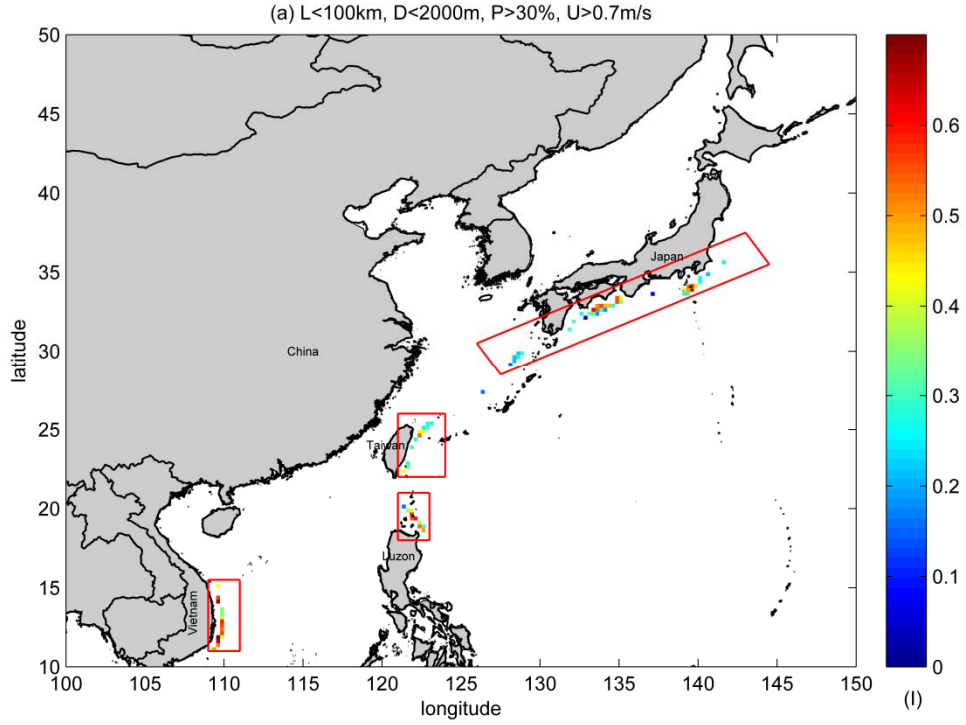
Figure 10. Selected sites in conditions of (a)L<100 km, D<2000m, P>30%, U>0.7 m s^{-1},

(b) L<50 km, D<2000m, P>30%, U>0.7 m s^{-1}, (c) L<50 km, D<1000m, P>30%, U>0.7

m s^{-1}, and (d) L<50 km, D<1000m, P>50%, U>1.0 m s^{-1}.
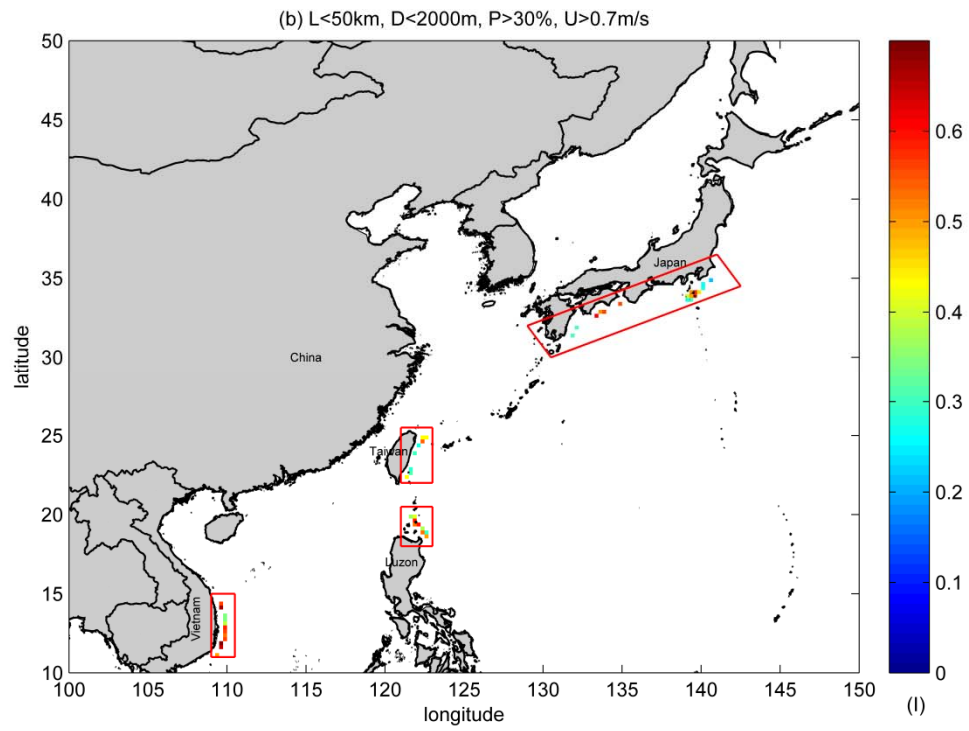
305

306   Figure 10. (continue)

307

(c) L<50km, D<1000m, P>30%, U>0.7m/s
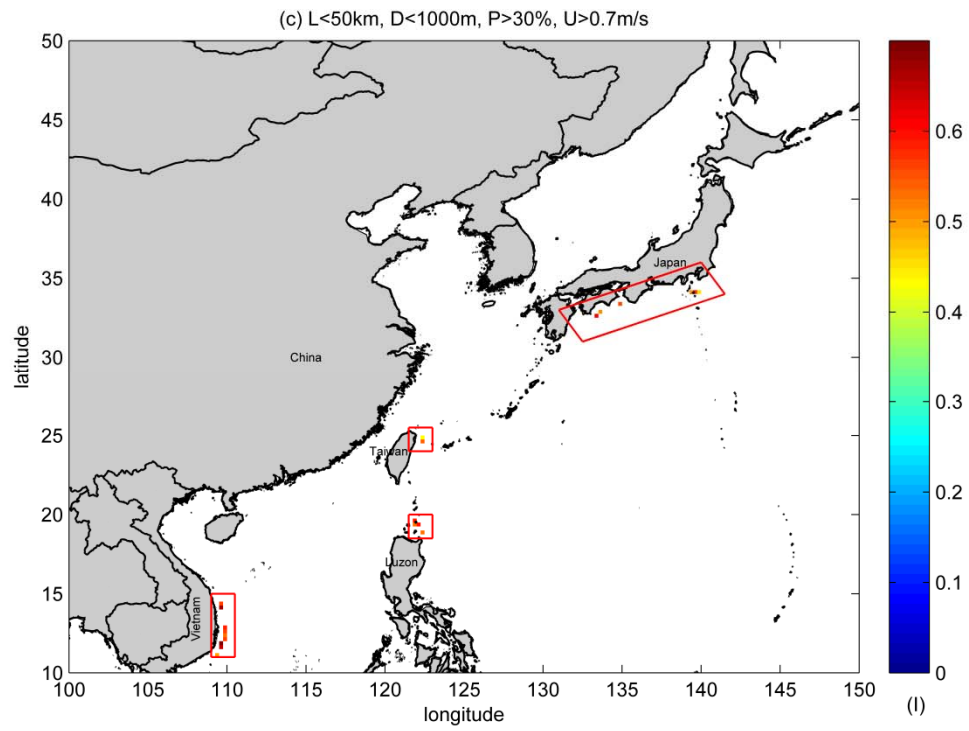
308

309   Figure 10. (continue)
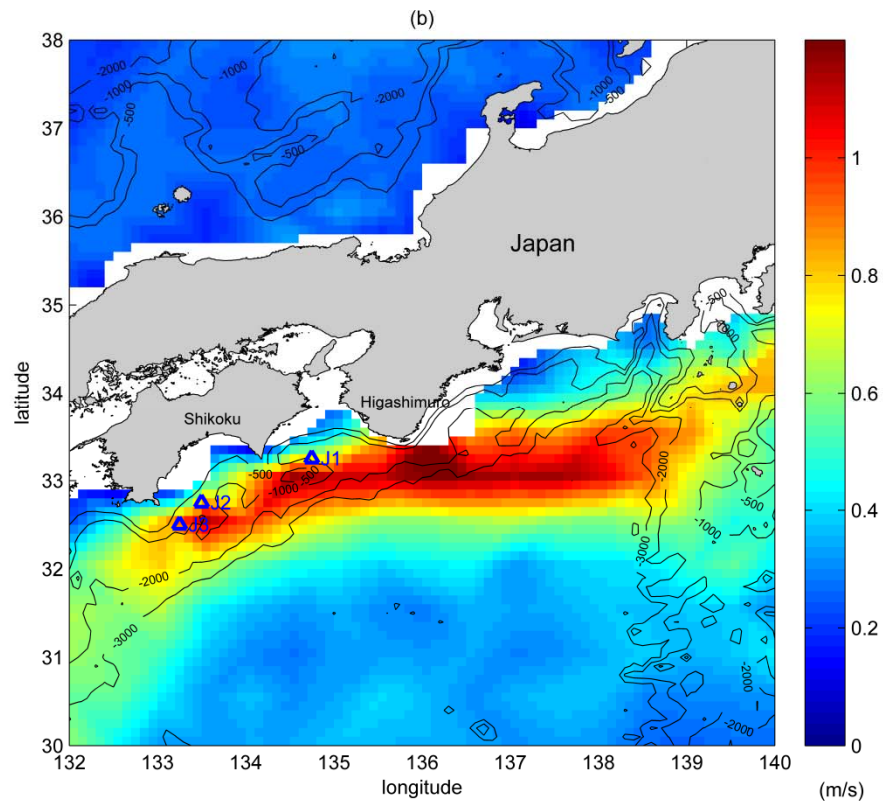
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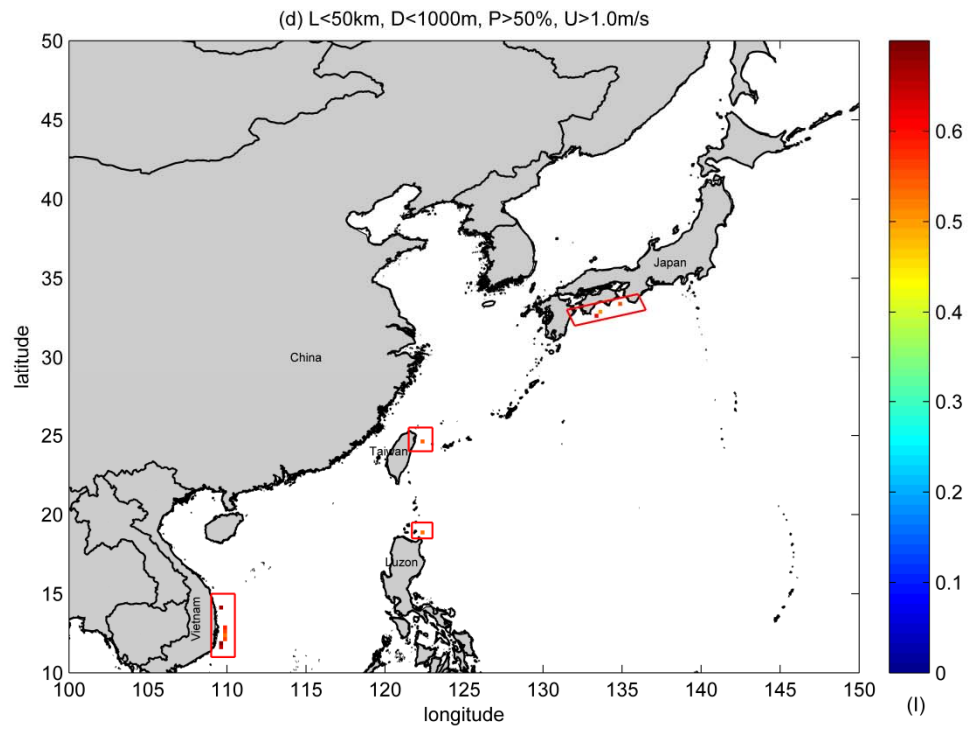
311

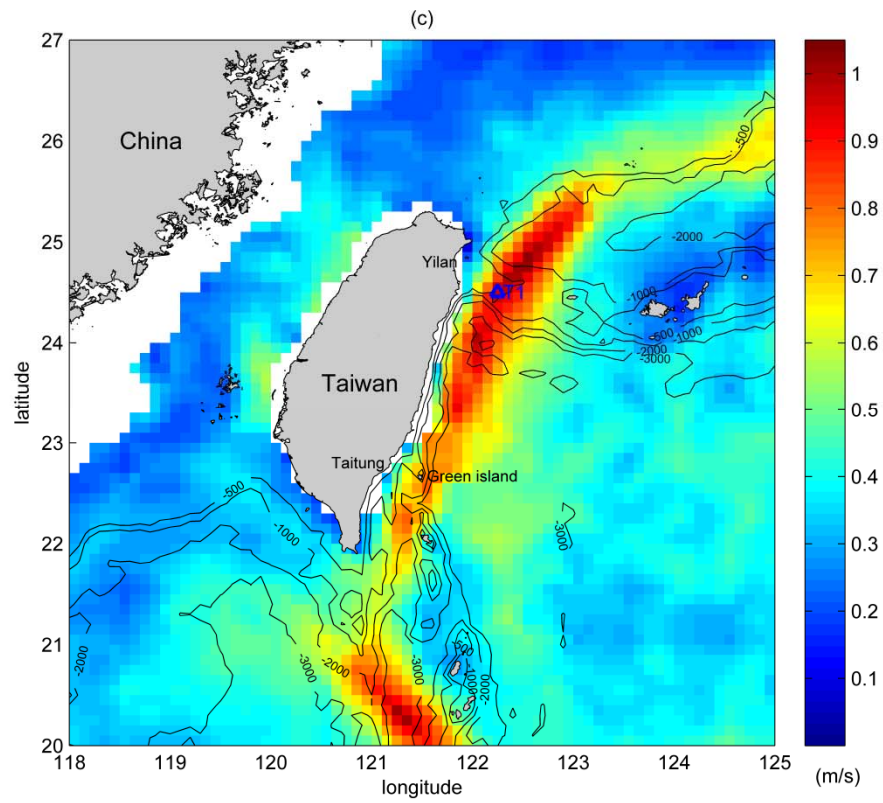312   Figure 10. (continue)

313
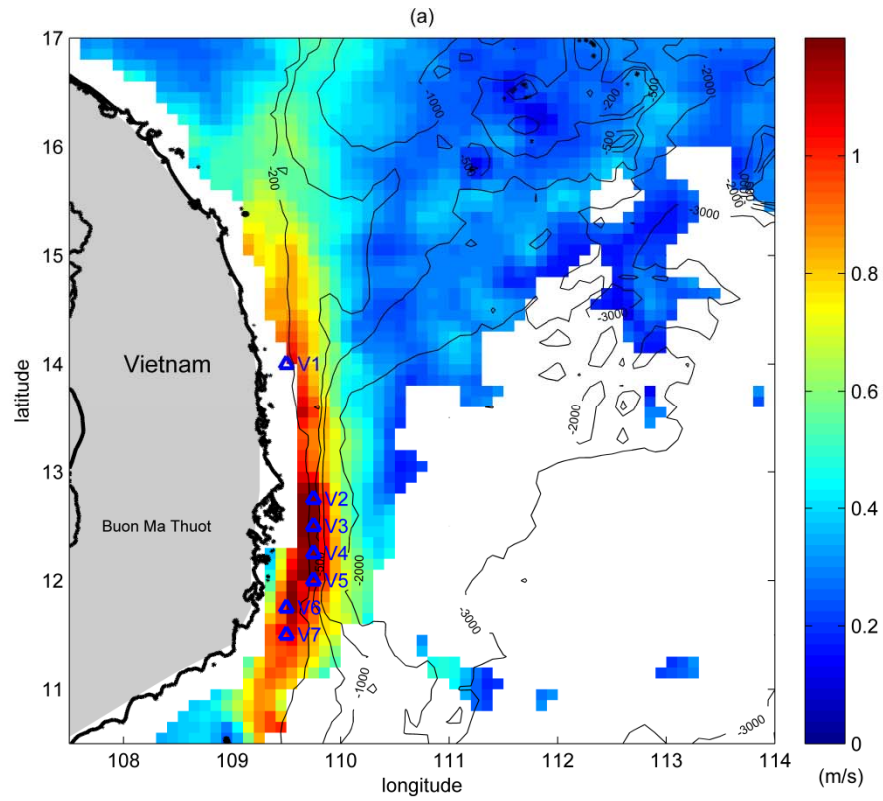
314

315   Figure 11. Enlargement of bin-averaged speed (a) east of Vietnam, (b) south of Japan, (c)

316   east of Taiwan, and (d) northeast of Philippines. The contour line is an isobath (unit: m).
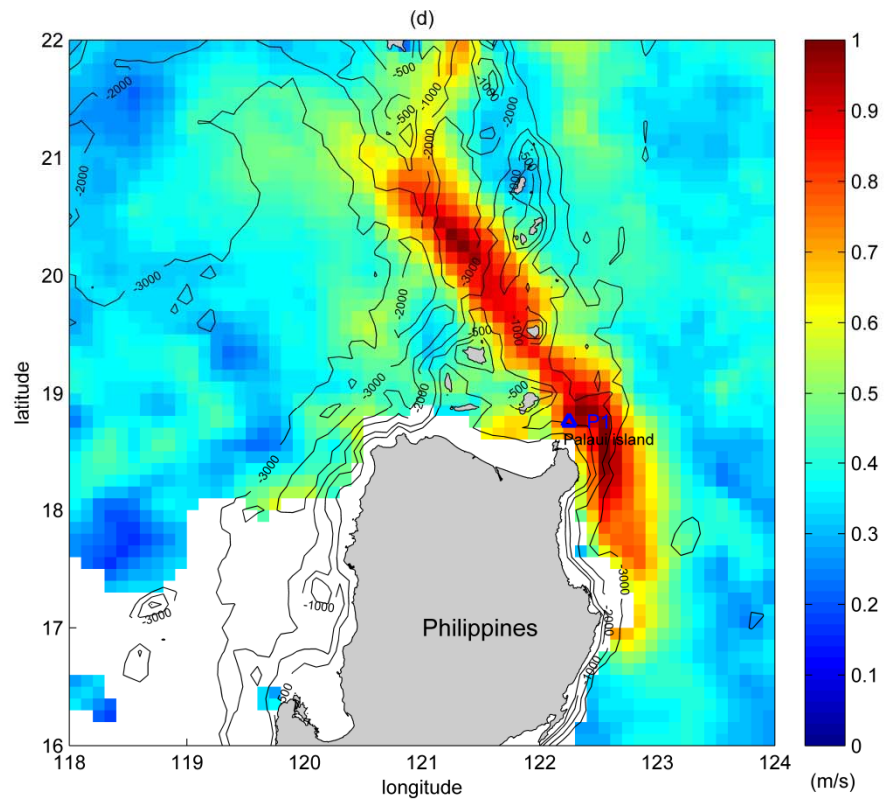
317

318   Figure 11. (continue)

319

320   Figure 11. (continue)

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323   Figure 11. (continue)

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